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# Experimental study of the performance of and emissions of low-speed diesel engine using various bio diesel blends at variable speed conditions: (Part I)

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## Abstract

The production of biodiesel from waste cooking oil to partially substitute diesel fuel to solver two problems: environmental pollution and energy shortage. The purpose of this study is to experimentally investigate the performance and emission of compression ignition engine using biodiesel extracted from waste cooking oils (WCO), such as (falafel frying oil, origin from palm oil. chicken frying oil; origin from soybean oil), and fresh soybean oil, and olive oil). After prepare biodiesel from WCO and fresh oils, was blended with pure diesel in two percentage are B20 (20% biodiesel from each type, 80% pure diesel), B10 (10% biodiesel from each type, 90% pure diesel). The biodiesel blends were used as an alternative fuel for diesel engine. After that, they were compared to pure diesel B00 (0% biodiesel, 100%pure diesel). The study investigates engine performance and emissions at constant load (2 kW) variable speed from (400-900 rpm). For engine performance, (brake power, brake specific fuel consumption, brake thermal efficiency) were analyzed. In addition, ($CO_2$, $O_2$, exhaust gas temperatures to indicate NOx) were analyzed. The results, shows that pure diesel produces higher brake power (BP) than all biodiesel blends. The highest value for brake specific fuel consumption (BSFC) is for pure diesel. The highest value for brake thermal efficiency BTE is for B10-S (10% biodiesel from soybeans oil, 90% pure diesel) is equal 27.6%. The B10-S produce highest value from NOx. Also, pure diesel produces higher $CO_2$ emissions than all biodiesel blends. All biodiesel blends produce higher $O_2$ emissions than pure diesel.

**Keywords:** Biodiesel; Diesel engine; Waste cooking oils; Performance; Emissions

## 1. Introduction

As the number of people around the world is increasing rapidly, as well as the technological sector is developing constantly; these changes make the matter of energy a top priority. Although many resources of energy are available, fossil fuels still the most useful source in producing energy.

According to ASTM, biodiesel is defined as "mono alkyl ester of long-chain fatty acids which is derived from vegetable oil". The chemical process which is used to make biodiesel is called transesterification. In this process, the triglycerides in vegetable oil are reacted with alcohol like (methanol), with the presence of a catalyst like (sodium hydroxide; NaOH), resulting two products, first; fatty acid methyl esters (FAME), Second; glycerin (a valuable by-product usually uses in soap and cosmetics) [1].

Biodiesel seems very suitable for many reasons. Firstly, it is a renewable source, secondly, it is the least toxic and most biodegradable. Moreover, it is reasonable for boilers and compression ignition engine (IC) without major modifications. Comparing to diesel, Biodiesel has more cetane number. Also, it does not contain aromatics or sulfur. Approximately, 10 to 11% of its weight is oxygen. These biodiesel properties reduce the emissions of carbon monoxide (CO),

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hydrocarbon (HC) and particulate matter (PM) in the exhaust gas compared to diesel fuel [2]. Also, the previous . Literature studies confirm when mix small amount from biodiesel with pure diesel, this will reduce emissions [3], and reduce the amount of greenhouse gases in the atmosphere and limit the phenomenon of global warming [2].

Some researchers proposed a model to predict the properties of biodiesel, such as viscosity, density, flash point, higher heating value (HHV), and oxidative stability based on saponification value, Iodine value and the polyunsaturated fatty acids content of feedstock. Biodiesel samples are produced from different types of oil. By using multiple linear regressions to obtain models in a high accuracy prediction for density and the higher heating value with an error less than 5% [4].

In another research, the impact of biodiesel blends on engine performance were studies and noticed that the best ratio of biodiesel blends help to better combustion is B20. Contributed to increase the power by 1.2%, the torque by 1.0%, and thermal efficiency by 1.2% [5].

Some researchers examined biodiesel produced from Jatropha seeds and fish residues to verify its effect on diesel engine emissions. This study indicated a decreasing in carbon monoxide, hydrocarbon, and soot emissions comparing with pure diesel [6].

Researchers studied the impact of biodiesel blends (B10, B20) that are produced from Jatropha, palm, algae, and waste cooking oils (WCO) on engine emissions, such as CO, CO2, NOx, HC, and smoke. The results show decreasing in CO, HC, $CO_2$, and smoke for biodiesel blends (B10, B20) produced from (Jatropha, algae, and palm) compared to pure diesel fuel. But an increasing in CO2 for biodiesel blends (B10, B20) produced from (WCO) compared to pure diesel. $NO_x$ emissions from all biodiesel blends (B10, B20) are higher than diesel fuel [7].

From this literature review, the importance of biodiesel in supporting energy security and reducing environmental pollution has been clarified. Also searching and identification of new feedstock for biodiesel production is vital. Therefore, this study focusses on the vegetable oil available in Jordan whether it is edible or non-edible to produce biodiesel fuel, to study its effect on engine performance and emissions, and to compare it with diesel fuel.

The objective of this paper is to investigate the effect of biodiesel blends on the performance of the internal combustion engine, and to Utilize waste cooking oils and fresh oil to produce biodiesel fuel.

## 2. Materials and method

### 2.1. Biodiesel Production Steps

A transesterification method was used to produce biodiesel. All equipment has been equipped to produce biodiesel, and it consists of the following:

Raw material (falafel frying oil, chicken frying oil, soybean oil, olive oil); methoxide (methanol / NaOH mixture); hotplate to heat the reactants; blender to mix reactants; Infrared thermometer; filter; bottle to store biodiesel. The following steps were used to make biodiesel (as illustrated in Fig 3.3).

- Step 1. Preparing WCO to produce biodiesel by heating it with a hotplate to 35 ° C, and then filtering it by using several layers of cheesecloth placed in a funnel.
- Step 2. Removing water from the WCO by heating the oil at a temperature of 60 degrees Celsius for about a quarter of an hour, then pouring the oil into another container, and leaving it until it settles for 24 hours, then re-pouring the oil into another container, taking into account not to pouring the water that will be stagnant at the end of the container.
- Step 3. Preparing 1000 cc of all kinds of oils and heated (65 C).
- Step 4. Preparation of methoxide solution (methanol / sodium hydroxide). When adding to WCO (falafel frying oil, chicken frying oil), mix (7gm) of sodium hydroxide with (220 cc) of methanol per liter of WCO. When adding to fresh oils (soybean, olive oil), mix (5gm) of sodium hydroxide with (200 cc) of methanol per liter of fresh oils.
- Step 5. Adding the methoxide solution to the oil and mixing in a blender for about 30 minutes
- Step 6. Putting the mixture in a bottle and waiting for 24 hours, and you will notice that there are two layers, a dark layer at the bottom which is glycerin, and a light layer at the top which is diesel.

- Step 7. Pouring biodiesel into another container and adding a small amount of distilled water to it and turning the bowl upside down several times for several minutes until the water draws the white soap.
- Step 8. Repeating the washing process 3 to 4 more times until the water becomes opaque, to make sure that all unwanted components have been removed and then drying the washed biodiesel samples at 110 ° C for 1 hour.

Blending process between biodiesel and pure diesel helping to improve viscosity. Because the use of biodiesel requires an engine modification. Two of the blends consisting of biodiesel produced from (soybean, olive oil, falafel frying oil, chicken frying oil) with diesel were prepared in the following ratios: B10 (10% biodiesel, 90% pure diesel), **B20** (20% biodiesel, 80% pure diesel), to study the effect of the difference in the proportion of biodiesel in fuels on the performance and emissions of the engine.

**Table 1** The physical properties of biodiesel blends

| Fuel type | Cetane number | Heating value kJ/kg | Density gm/cc |
|---|---|---|---|
| Diesel | 47 | 43400 | 0.8550 |
| B20 (olive) | 49.20 | 42818 | 0.8656 |
| B20 (soybean) | 48.60 | 42180 | 0.8594 |
| B20 (falafel frying oil) | 48.40 | 42651 | 0.8642 |
| B20 (chicken frying oil) | 47.03 | 42326 | 0.8566 |
| B10 (olive) | 48.10 | 43109 | 0.8603 |
| B10 (soybean) | 47.80 | 42790 | 0.8572 |
| B10 (falafel frying oil) | 47.70 | 43025 | 0.8596 |
| B10 (chicken frying oil) | 47.02 | 42863 | 0.8558 |

### 2.2. Experimental Equipment's Specifications

The type of engine used in this research is a Lister, single cylinder, four strokes, water cooled, computer controlled. Table 2 explains the technical specifications of the engine. The testing engine is depicted in Figure 1. To measure the exhaust emissions of a diesel engine, a KANE455 Infra-Red Analyzer was used. The details of the exhaust gas analyzer are shown in Table 3.4. To get the average values, all tests were repeated two times.

**Table 2** Engine Specification

| Model | Diesel engine |
|---|---|
| Type | Lister, Four Stroke (CI) Diesel Engine, Water Cooled |
| No. of Cylinders | Single Cylinder |
| No. of Strokes | 4 |
| Bore | 114.3 mm |
| Speed | 1000 rpm |
| Power | 6 kw |
| Stroke Volume | 1.433 L |

**Figure 1** Internal Combustion Diesel Engine (Test set up)

### 2.3. The Experimental Set-Up

The experimental investigation was performed on a biodiesel blend (B10 and B20) that was produced from (olive oil, soybeans, falafel frying oil, chicken frying oil. And comparing it with B00 (00% biodiesel, 100% pure diesel) to see the extent of the effect of biodiesel on engine performance and emissions. The experimental investigation for each blend of biodiesel were performed at constant load and variable speed.

When conducting an experiment. Firstly, operating diesel engine for 15 minutes to warm up the engine before running by B10 and B20 blends. The fuel consumption rate was determined by using the glass burette and stopwatch. The engine speed and its force were measured by using analog tachometer.

## 3. Results and discussion

The type of fuel has an important role in influencing engine performance and emissions. Biodiesel blends have a significant impact on engine performance and emissions, due to their high oxygen content, high density, low heating values, and high cetane, as show in Table 1.

In this section the biodiesel blends are divided into two groups, the first group is biodiesel produced from WCO such as (B20-C, B10-C, B20-F, and B10-F). The second group is biodiesel produced from fresh oils such as (B20-O, B10-O, B20-S, and B10-S). We will discuss the effect of each group of biodiesel blends on engine performance such as (brake power (BP), brake specific fuel consumption (BSFC), brake thermal efficiency (BTE)), and emissions such as ($CO_2$, $O_2$, exhaust temperature to indicate $NO_x$).

### 3.1. Brake Power (BP)

The brake power (BP) of an IC engine is the power that is produced at the crankshaft.

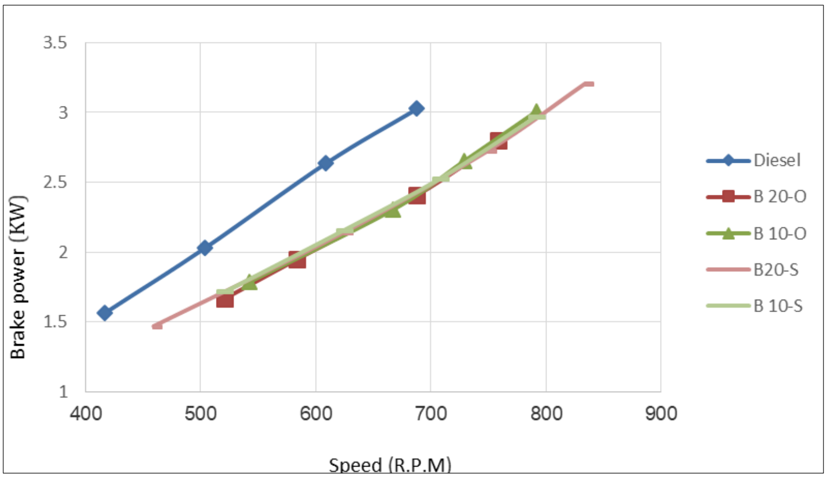


**Figure 2** Brake power as a function of engine speed

Figure 2 shows brake power as a function of engine speed (rpm). Obviously, the brake power of pure diesel and all biodiesel blends increase with increasing speed. The brake power of pure diesel is higher than biodiesel blends, because of the heating value (HV) of pure diesel is higher than all biodiesel blends, as shown in Table 1. The average of increasing in BP for pure diesel compared to all biodiesel blends is about 30%.

Figure 3 shows the brake power as a function of engine speed (rpm). Obviously, the brake power of pure diesel and all biodiesel blends increase with increasing speed. The brake power of pure diesel is higher than biodiesel blends. Also, the brake power of (B20-F) is also the highest among other biodiesel blends produced from WCO. The reason higher brake power for pure diesel and (B20-F) is mainly due to their respective higher heating value (HV), as indicated in Table 1. The average of increasing in BP for pure diesel compared to B20-F is about 25%.

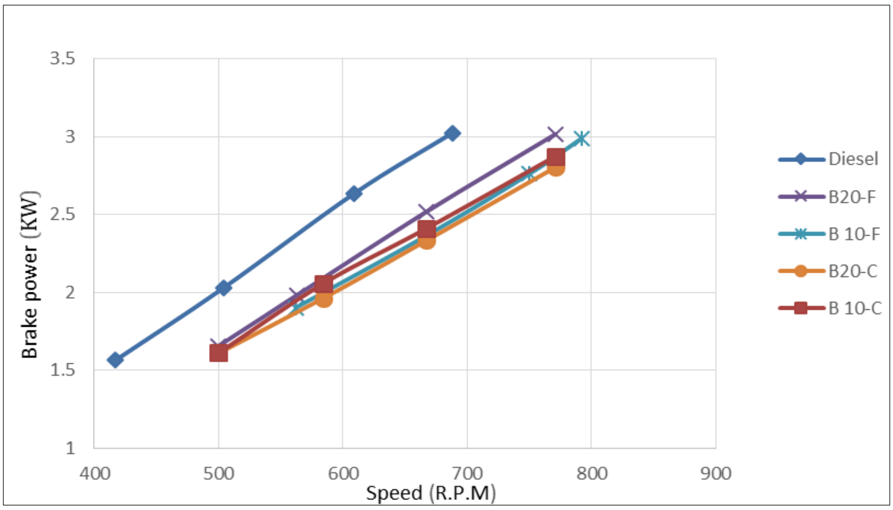


**Figure 3** Brake power as a function of engine speed

### 3.2. Brake Specific Fuel Consumption (BSFC)

The brake specific fuel consumption (BSFC) is defined as the ratio of the mass flow rate of fuel and the brake power, and it reflects how good the engine performance is. It is desirable to obtain a lower value of BSFC meaning that the engine uses less fuel to produce the same amount of power. This parameter was tested in two cases.

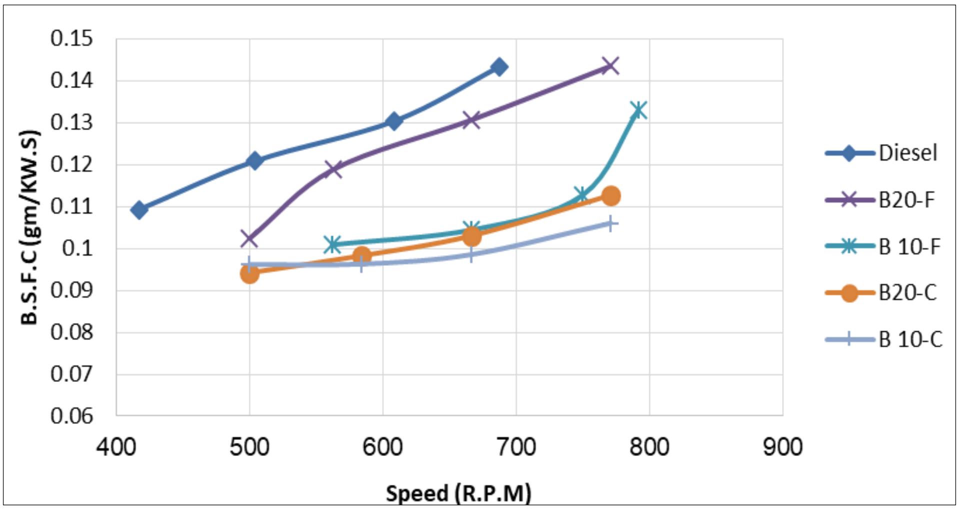


**Figure 4** Brake specific fuel consumption (B.S.F.C) as a function of engine speed

Figures 4 and 5 show the BSFC as a function of engine speed. The BSFC is the ratio of mass fuel consumption to the brake power, it is a measure of the capability of the engine in converting fuel to brake power. It is desirable to have lower BSFC meaning that the engine uses less fuel to produce the same amount of power. In both figures the BSFC of pure diesel and all biodiesel blends increase with increasing speed. Also, in both figures the highest value of BSFC is for pure diesel is equal (0.143 gm/wk.'s), because it has the highest fuel consumption. The lowest values of BSFC among of biodiesel blends in figure 4.5 is B10-C, the average increasing in BSFC for pure diesel compared to BSFC for B10-C is about 26 %. Also, the lowest values in figure 4.6 is B10-S, the average increasing in BSFC for pure diesel compared to BSFC for B10-S is about 23.7%.

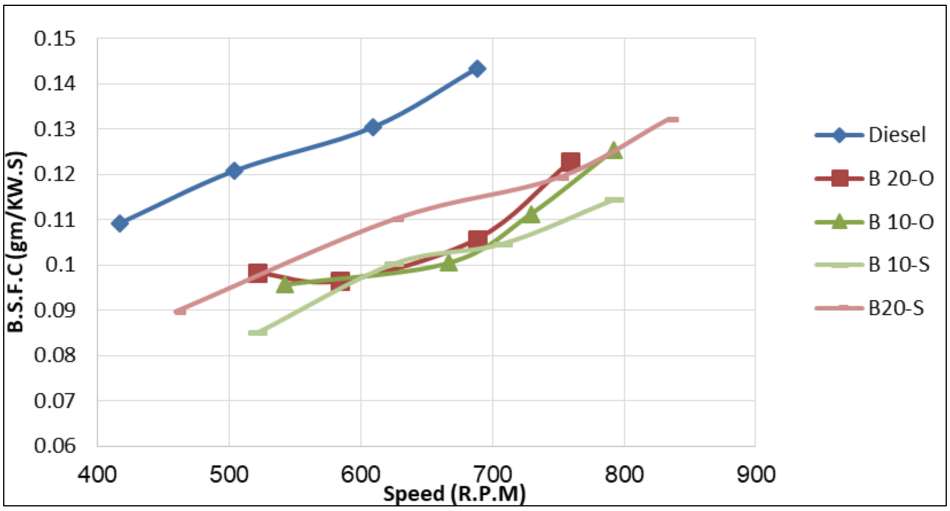


**Figure 5** Brake specific fuel consumption (B.S.F.C.) as a function of engine speed

### 3.3. Brake Thermal Efficiency (BTE)

Brake Thermal efficiency (BTE) is defined as the brake power of a heat engine as a function of the thermal input from the fuel. It is used to evaluate how well engine converts the heat from a fuel to mechanical energy.

Figures 6 and 7 show the Brake thermal efficiency (BTE) as a function of speed. It is clear from the figures that the BTE decreases with increasing in engine speed. In both figures the BTE for all biodiesel blends is higher than pure diesel. The highest value of BTE in figure 4.9 is for B20-C is equal 25%, the average increasing in BTE for B20-C compared to BTE for pure diesel is about 56.3 %. Also the highest value for BTE in figure 4.10 is for B10-S is equal 27.5%, the average increasing in BTE for B10-S compared to BTE for pure diesel is about 55 %. The reason for the increase in BTE of biodiesel blends is the higher oxygen content, which leads to more complete combustion and higher thermal energy production in the engine.

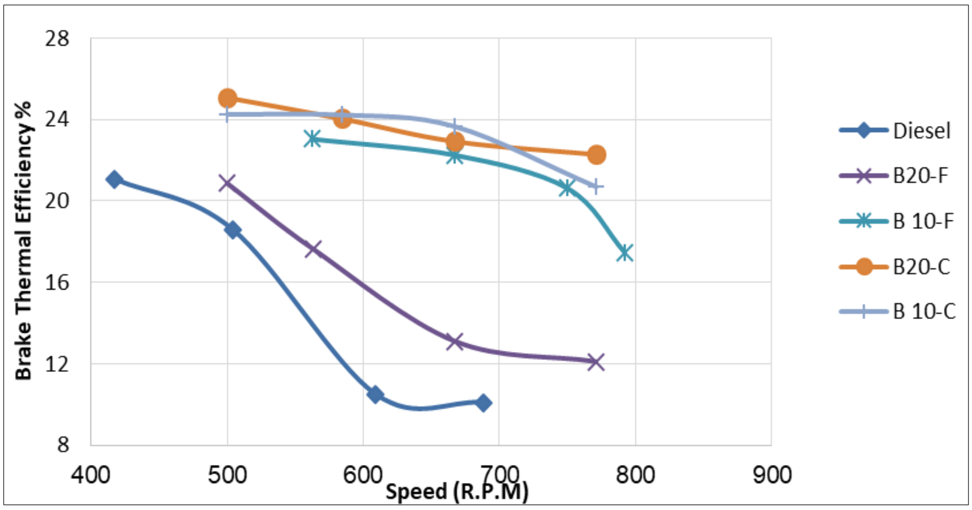


**Figure 6** Brake Thermal Efficiency as a function of engine speed

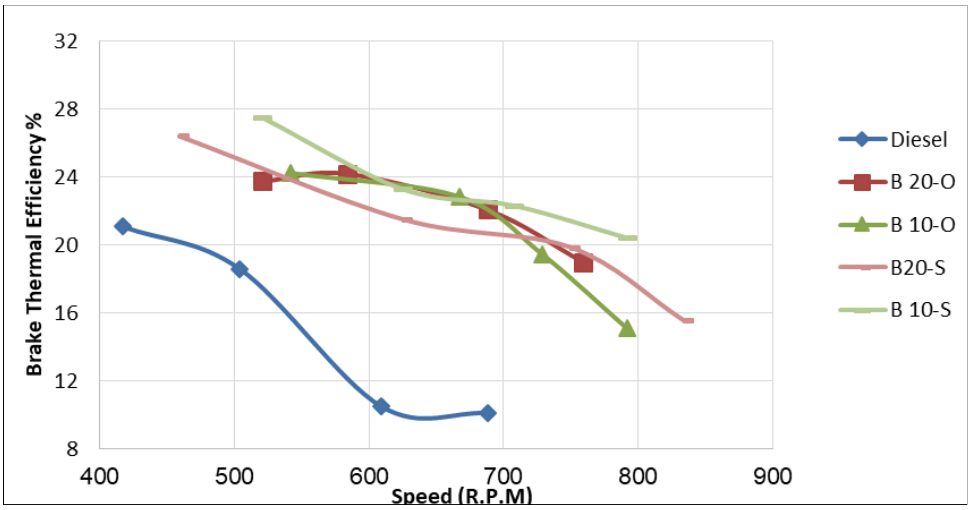


**Figure 7** Brake Thermal Efficiency as a function of engine speed

### 3.4. Exhaust Temperature

Engine exhaust temperature has been considered as one of the important parameters. It is a good parameter in analyzing the exhaust emissions especially for NOx. When the exhaust temperature increases, the emitted nitrogen oxides will increase.

Figures 8 and 9 show the exhaust gas temperature as a function of engine speed. It is clear in both figures that the exhaust gas temperature increases with increasing speed for all tested fuels. The exhaust temperature is a vital parameter in the analysis of exhaust gases, especially NOx. The higher the exhaust temperature is, the higher the emissions of NOx will be. In both figures the exhaust gas temperature of all biodiesel blends is lower than pure diesel. This is because pure diesel has higher heating value than all biodiesel blends. Thus, pure diesel produces NOx more than all biodiesel blends.

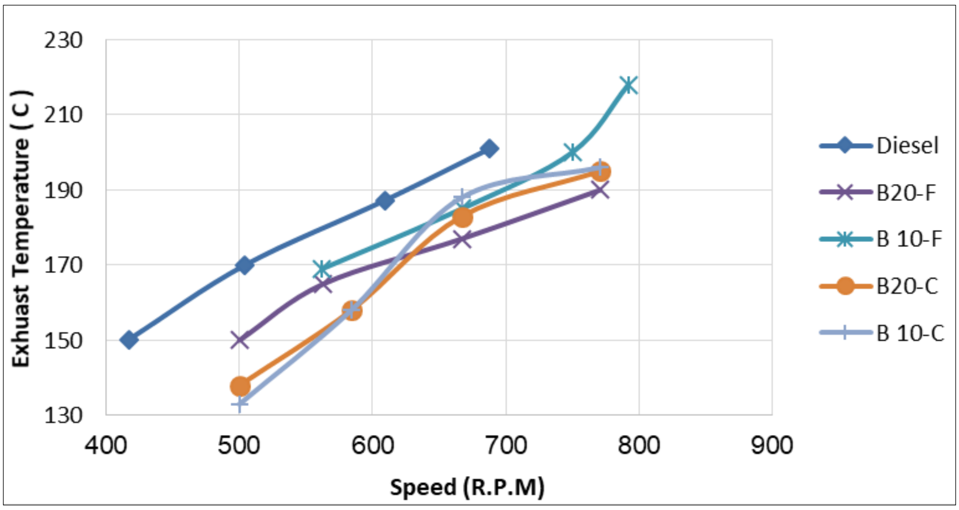


**Figure 8** Exhaust Temperature as a function of engine speed

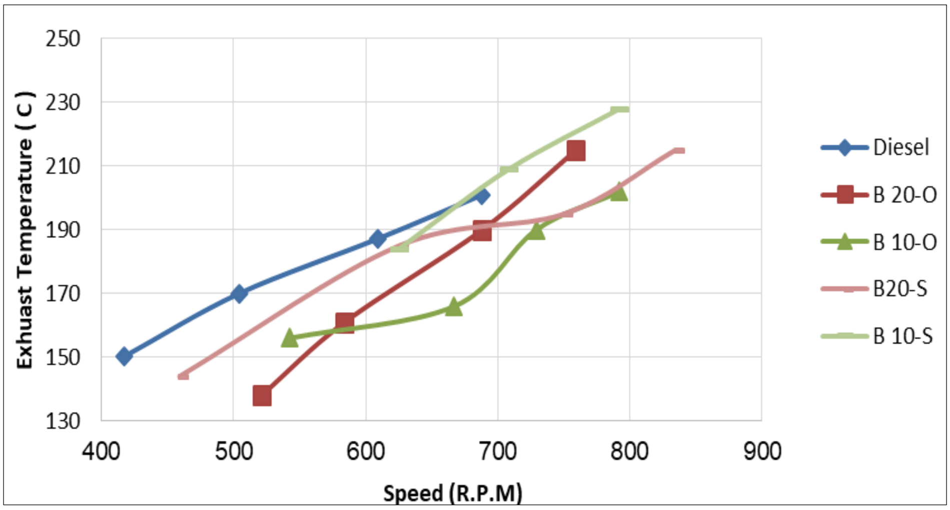


**Figure 9** Exhaust Temperature as a function of engine speed

## 4. Conclusion

The experimental results of this study lead to the following conclusions:

- The biodiesel blends can be used as an alternative fuel for compression ignition engine without modification on it.
- The average increasing in BP for pure diesel compared to BP for biodiesel produce from fresh oil is about 30%. The average increasing in BP for pure diesel compared to BP for biodiesel produce from WCO (B20-F) is about 25%.
- The lowest value of BSFC for biodiesel that produce from WCO is B10-C, which is 26% lower than the BSFC of pure diesel. Also, the lowest BSFC value of biodiesel that produce from fresh oil is B10-S, which is 23.7% lower than the BSFC of pure diesel.
- The highest value of BTE for B10-S is equal 27.5%, the average increasing in BTE for B10-S compared to BTE for pure diesel is about 55 %.
- Reducing the proportion of biodiesel in the blends contributes to the increasing in brake thermal efficiency.
- After experimental investigate for biodiesel blends, the best biodiesel from all biodiesel blends is B10-S, because it has lowest BSFC and highest BTE compared to pure diesel Also, it is less harmful to the environment compared to other types.

## Compliance with ethical standards

### *Acknowledgments*

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### *Disclosure of conflict of interest*

All authors declare that they have no conflict of interest.

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